Assessing the Accuracy of Geodetic Measurements from the VLBI2010 Observing Network

G11A - 0632

D. S. MacMillan[1], A. Niell[2], and J. M. Gipson[1]

[1] NVI, Inc., NASA Goddard Space Flight Center, [2]MIT Haystack Observatory

Introduction

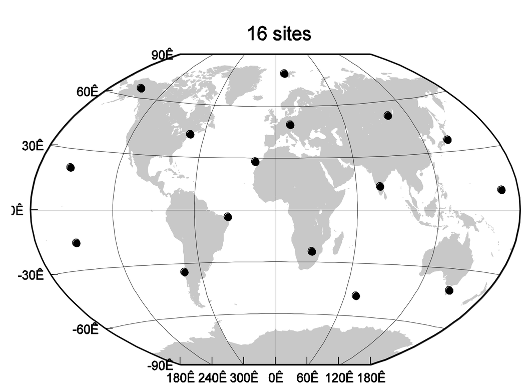
The IVS (International VLBI Service for Geodesy and Astrometry) is designing a new observing system called VLBI2010 [Niell et al., 2005] consisting of a global network of small (at least 12 m diameter) fast-slewing antennas. The IVS has investigated the geodetic performance of a future network of VLBI2010 antennas by simulating the performance of different antenna networks and observing scenarios. In previous work we investigated the expected precision of the system using Monte Carlo simulations. Here we focus more on the expected accuracy and any systematic effects. To do this, we performed simulations of the network using known input error contributions: troposphere turbulence, clock delays, measurement noise, troposphere mapping function error, antenna gravitational deformation, and site pressure error. Measures of precision and accuracy are scatter and bias of station position estimates and EOP estimates.

Simulation Models and Procedure

As a tool for the design of VLBI2010, we developed a Monte Carlo simulation procedure to study the effect on estimated geodetic parameters. Simulations were performed with the Calc/Solve (least-squares) software package at NASA Goddard Space Flight Center. The simulation process begins with the generation of a schedule of observations. We then compute input simulated noise for the scheduled observations,

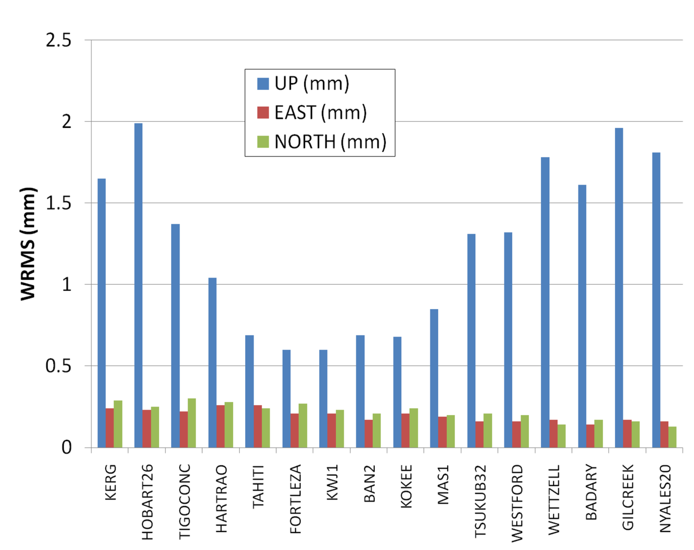
$$O-C=[m_{wet}(el_2)\tau_{wz2}+clk_2+\tau_{s2}]-[m_{wet}(el_1)\tau_{wz1}+clk_1+\tau_{s1}]+\sigma_{obs}$$

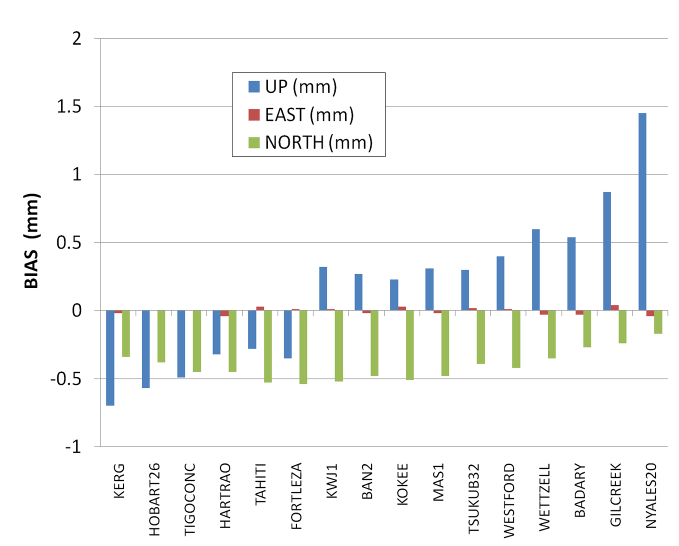
Here, m_{wet} is the wet troposphere mapping function evaluated at observation elevation angles el_1 and el_2 at station 1 and 2. The τ_{wz} and clk terms are the wet zenith delays and clock delays at the two sites. The τ_s terms are other site-dependent errors. The observation uncertainty is given by the white noise contribution σ_{obs}. We simulated the effects of the different error sources using a network of 16 globally-distributed sites.



	Lat	Lon		Lat	Lon
KERG	-49	70	KOKEE	22	-160
HOBART26	-42	147	MAS1	27	-16
TIGOCONC	-36	-73	TSUKUB32	36	140
HARTRAO	-25	27	WESTFORD	42	-71
TAHITI	-17	-149	WETTZELL	49	13
FORTLEZA	-5	-35	BADARY	51	102
KWJ1	9	167	GILCREEK	64	-147
BAN2	13	78	NYALES20	78	12

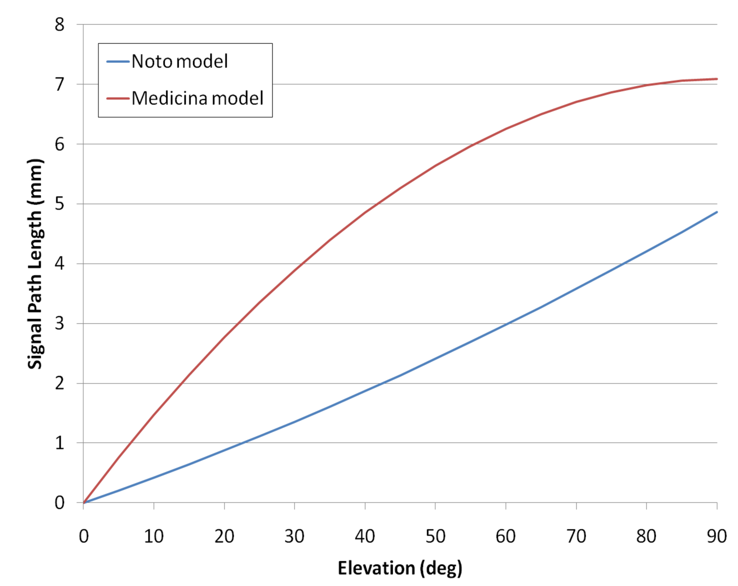
1 Troposphere Mapping Function Error

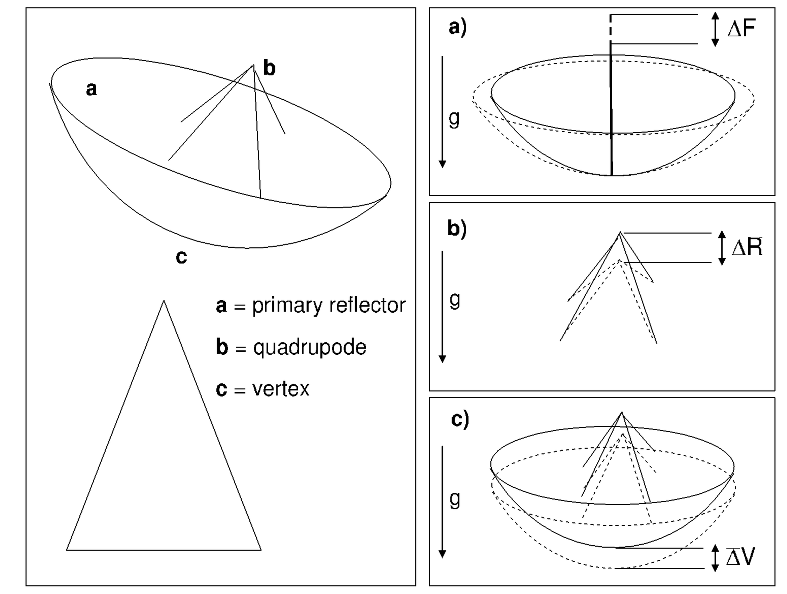




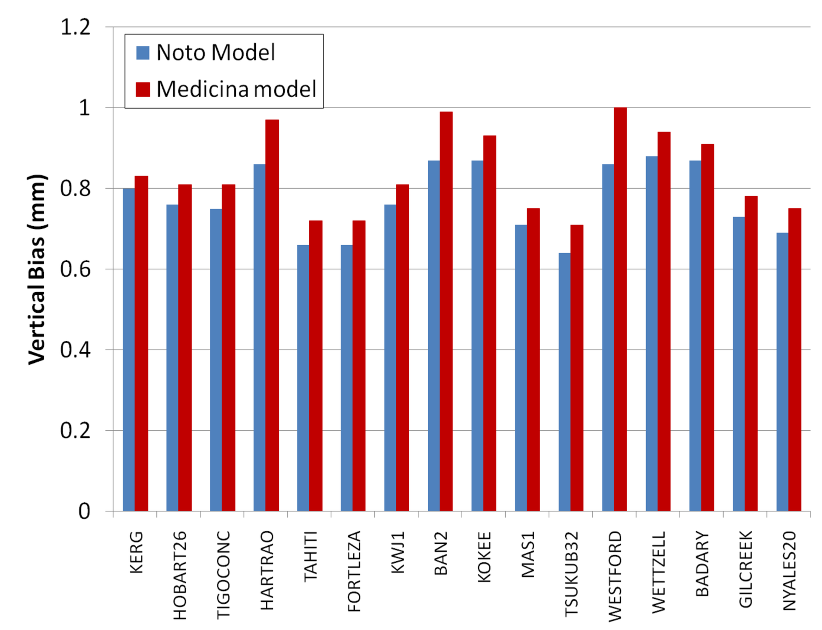
Currently the most accurate troposphere mapping functions in common use are the Vienna mapping functions,VMF1 [e.g.,Boehm et al.. 2006]. These are derived by one-dimensional raytracing of spatially interpolated ECMWF troposphere P, T, RH profiles at 6-hour intervals. For our simulation, we used estimates of the precision and accuracy of the hydrostatic VMF1 mapping function based on comparisons with raytracing radiosonde profiles. VMF1 precision as a function of latitude was estimated by Niell [2006]. Boehm et al. [2006] provides the accuracy of VMF1. The resulting bias and precision **ordered by latitude** for site UEN positions for the 16-site network shows the effect of the latitude-dependent error. If we had used the seasonal hydrostatic GMF or NMF mapping functions, the wrms and bias errors would be about a factor of 3 greater.

2 Antenna Gravitational Deformation





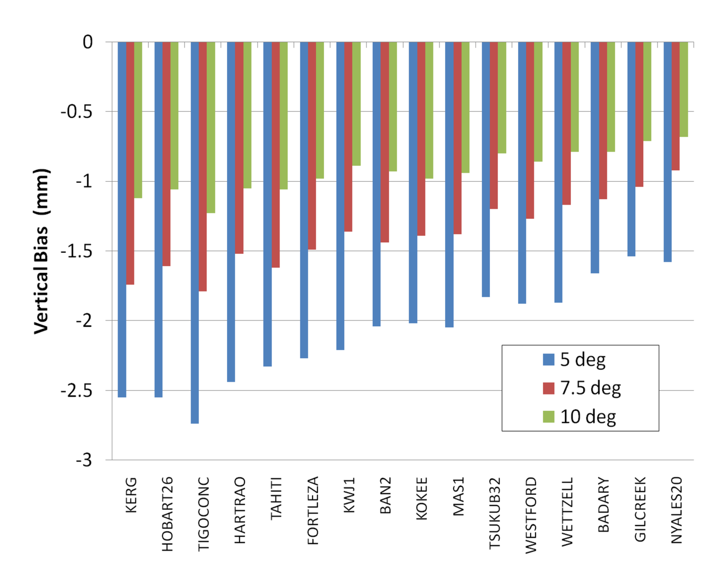
$$\Delta L(e)=\alpha_F\Delta F(e)+\alpha_V\Delta V(e)+2\alpha_R\Delta R(e)$$



Recently Sarti et al. [2009] measured the elevation dependence of the gravitational deformation of the 32-meter VLBI antennas at Noto and Medicina in Italy. They express the excess path delay, ΔL(e), due to gravitational deformation as a linear combination of the change in focal length ΔF, change in antenna dish vertex position ΔV, and change in receiver position ΔR – shown in the diagram above. The expression here is for Cassegrain antennas where the signal is reflected from the primary surface and then by a subreflector (mounted looking inward from the quadrupod) back down to the receiver. This accounts for the factor of 2.

Here we have taken the models for the Noto and Medicina antennas [Abbondanza and Sarti, 2010] and scaled them down from 32 meters to the 12-meter VLBI2010 size assuming that the deformation scales as the square of the antenna diameter.. The elevation dependence of the signal path ΔL(e) for the two cases are plotted above. The difference between the curves is caused by a decrease in the Noto focal length term, ΔF, by almost a factor of 2 due to an upgrade of the primary reflector to an adaptive surface. Despite this, the resulting vertical biases in the above bar graph from the two models are not significantly different.

3 Site Pressure Error



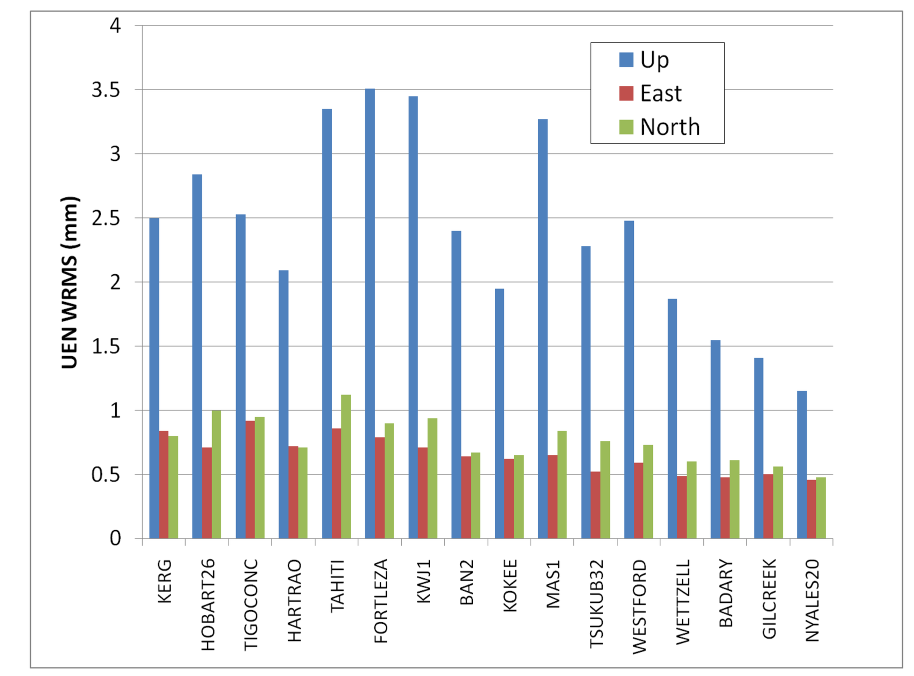
The zenith hydrostatic troposphere delay is proportional to the surface pressure. Errors in the site pressure will propagate into the estimates of the site vertical and the wet zenith delay. This happens because the hydrostatic ('dry') and wet mapping functions are different (the scale heights of the dry and wet troposphere ~10 km and ~2-3 km). We simulated the effect of a 10 mbar pressure bias at each site (about 23 mm of delay). We ran simulations for minimum elevation cutoffs of 5, 7.5, and 10 degrees. The resulting biases decrease by about a factor of 2 over this range of cutoffs. This simulation shows the obvious importance of making site pressure measurements as well as in maintaining accurate barometer calibrations.

See poster G53B-0728: "Impact of Erroneous Meteorological Data on VLBI processing", by Gipson et al.

4 Troposphere Turbulence Error

Our turbulence model is based on the analysis of Treuhaft and Lanyi [1987]. This model assumes that the refractivity of wet troposphere fluctuations is described by Kolmogorov turbulence. We follow a procedure described by Nilsson et al. [2007] to generate turbulent delays.

We applied a latitude-dependent model for the refractive index structure constant C_n. It is based on analysis by T. Nilsson [personal communication] of high resolution radiosonde data from a set of globally distributed sites. Using his estimates of C_n and H, we derived a latitude-dependent model for C_n. Additionally, we apply a site height scale correction factor.



We ran this turbulence model using a 24-hour observation file with different input simulated noise for each of 100 repetitions. We also added a clock error contribution (Allan standard deviation of 10^{-14} at 50 minutes) and observation noise of 4 ps. The resulting UEN site wrms scatter **ordered by latitude** increases as latitude decreases. The biases (not shown) are significantly less than 1 mm. Some sites (Kokee, Hartrao, BAN2) appear to have anomalously low scatter, but this is because their altitude are significant (800-1100 m).

Conclusions and Future Work

- Biases at the 1-2 mm level in site position estimates can arise from several sources including (1) troposphere mapping function error, (2) gravitational antenna deformations, (3) site pressure errors.
- The gravitational deformation of VLBI2010 antennas needs to be directly measured since extrapolating results from the large 32-meter Italian antennas is not necessarily reliable.
- Errors due to (4) troposphere turbulence have latitude dependence but do not result in significant biases
- Further work will be done to determine possible systematic effects on EOP estimates and wet troposphere parameter estimates
- We will also investigate the dependence of estimated parameter biases on the rate that stations observe (here we only considered the case of 60 observations/hour)

References

Abbondanza, C. and P. Sarti, Effects of illumination functions on the computation of gravity-dependent signal path variation models in primary focus and Cassegrainian VLBI telescopes, J. Geod, 84, 515-525, 2010.

Boehm, J., A. Niell, P. Tregoning, and H. Schuh, Global Mapping Function (GMF): a new empirical mapping function based on numerical weather model data, Geophys. Res. Lett., 33, 2006.

Niell, A.E. et al., VLBI2010: Current and future requirements for geodetic VLBI systems, Report of Working Group 3, 2005.

Niell, A., Interaction of atmospheric modeling and VLBI analysis strategy, Proc. IVS 2006 General Meeting, 252-256, 2006.

Nilsson, T., R. Haas, and G. Elgered, Simulations of atmospheric path delays using turbulence models, Proc. 18th European VLBI for geodesy and astrometry working meeting, 175-180, 2007.

Sarti, P., C. Abbondanza, L. Vittuari, Gravity-dependent signal path variation in a large VLBI telescope modeled with a combination of surveying methods, J. Geod., 83, 1115-1126, 2009.

Treuhaft, R.N. and G.E. Lanyi, The effect of the dynamic wet troposphere on radio interferometric measurements, Radio Sci., 22, 251-265, 1987.

Information Contact: Dan MacMillan
NVI, Inc and NASA Goddard Space Flight Center

E-mail: daniel.s.macmillan@nasa.gov